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Dickie, R., & Cahill, R. (2017). New Electronic Switching Arrangement for mm Wave Radioameter Calibration. In Proceedings of 38th ESA Workshop on Innovative Antenna Systems and Technologies for Future Space Missions for Space Applications, European Space Agency Holland: ESA.

### Published in:

Proceedings of 38th ESA Workshop on Innovative Antenna Systems and Technologies for Future Space Missions for Space Applications, European Space Agency

### Document Version:

Peer reviewed version

### Queen's University Belfast - Research Portal:

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# NEW ELECTRONIC SWITCHING ARRANGEMENT FOR MM-WAVE RADIOMETER CALIBRATION

R. Dickie<sup>(1)</sup>, R. Cahill<sup>(1)</sup>

<sup>(1)</sup>Institute of Electronics, Communications and Information Technology (ECIT)

Queen's Road, Queen's Island, Belfast BT3 9DT, UK, Email: r.dickie@ecit.ac.uk; r.cahill@ecit.qub.ac.uk

**Abstract** – This paper describes a quasi-optical calibration switch arrangement that can be used to reduce the demands imposed on the antenna scan motor for passive radiometers. The work addresses the need to replace bulky motor driven scan mechanisms that are currently used on millimetre and submillimetre wave EO radiometers. This will provide a major reduction in payload mass, footprint, power consumption and increase instrument reliability. Key components in the system are electronically reconfigurable Frequency Selective Surface's (FSS's) that control the signal transmission to calibration targets and scene radiation in the network. Two switching methods, liquid crystal and piezoelectric actuators have been investigated, and a numerical study carried out on their RF performance.

## I. INTRODUCTION

Millimeter and submillimetre wave radiometers are employed for remote sensing of the Earth from satellite platforms for global meteorology, oceanography and climatology studies [1]. In radiometric scanned measurements, the strength of the thermally radiated signals at each frequency is determined as a radiometric equivalent temperature by interpolating between signal levels measured when the radiometers beam is filled in turn by two black body calibration sources at differing, known temperatures. The calibration principle is based on the linearity of the receiver chain [2]. Current radiometers such as AMSU-A, AMSU-B [1] and MHS [3] employ cross-track scanning systems to view the Earth. MHS must be calibrated every scan, the cold calibration may be the external cosmic background away from the Earth, at a temperature of 3K, and the other an on board target normally at local ambient temperature. Limbsounding is another remote sensing scan profile [4] in which the radiometer is directed towards the horizon, and vertical distributions are explored by 'tilting' a high gain reflector antenna. Hot calibration is performed by using a mechanical switching mirror in the receiver often to direct the feed horn towards the warm onboard calibration target

(OBCT). High elevation angle views of the sky can be sufficiently contaminated by spectral features, requiring on board cold calibration as well. Both cold (liquid argon cooled pyramidal absorber) and hot calibration (conical absorber) is therefore performed using on-board loads typically maintained at 88 K and 300 K respectively.

The proposed method can be used to reduce the demands imposed or even replace the mechanical systems for hot and cold radiometric calibration. An overview of the arrangement is depicted in Figure 1, along with a beam steering sub-reflector and static parabolic reflector. Combined these provide full electronic control, with the sub-reflectors beam scanning implemented using liquid crystal (LC) [5] or MEMS type actuators (not discussed further for brevity).

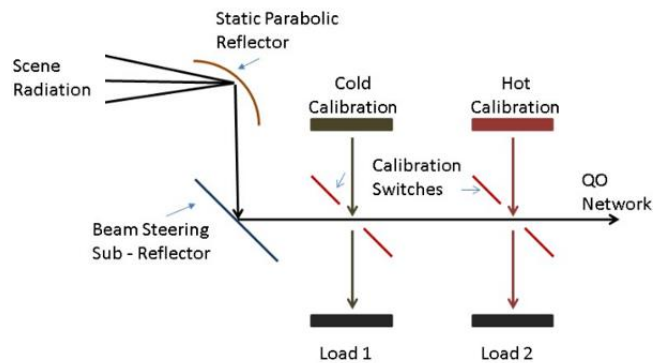


Figure 1: On board electronic calibration concept based on two FSS switches.

The instrument's calibration operates by switching between cold and hot OBCT's and directing discrete samples of these to the mixer detectors in the quasi-optical receiver. All the components aside from the parabolic reflector can be accommodated within the thermally controlled quasi-optical feed train of the instrument.

## II. CALIBRATION SWITCHING METHOD

The quasi-optical calibration switch is obtained by reconfiguring the spectral response of two bandpass FSS filters, the method is shown in Figure 2. For hot calibration both FSS are switched to reflection mode, opening the hot target channel to the receiver in the QO network. For cold calibration the first FSS in the network is switched to reflection mode and second FSS is switched to transmission mode, providing an open channel from the cold target to the receiver. For scene radiation capture, both FSS switches operate in transmission providing an open channel from the receiver to the scene, this configuration is shown in Figure 1.

The FSS provides signal transmission with low insertion loss when the bandpass spectral response is positioned at the centre of the operating frequency band. For switching off the signal the filters stopband response is shifted into the operating frequency band. Providing a signal band that can be dynamically reduced and therefore high isolation is obtained.

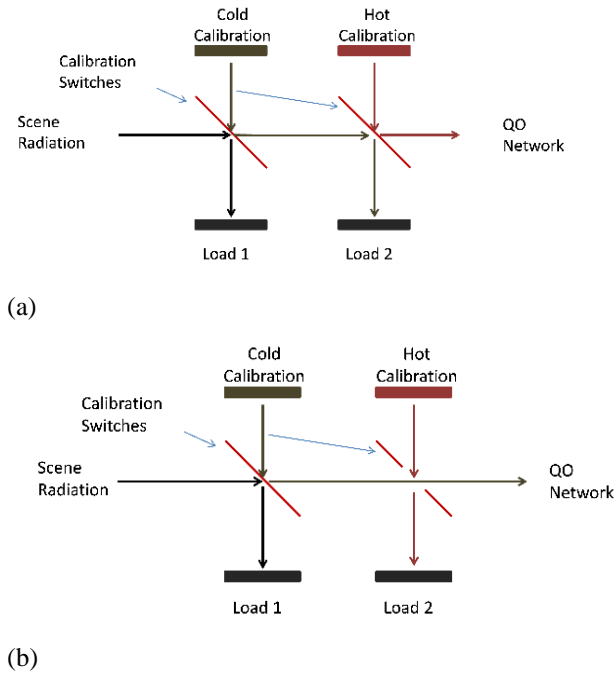


Figure 2: Proposed electronic calibration switch concept, (a) hot calibration (b) cold calibration.

In this paper two different methods for reconfiguring the filter response are investigated. Both these have the potential to provide low insertion loss, wide bandwidth and high switching speed.

## III. LIQUID CRYSTAL MATERIAL ACTUATED FSS

Electronic control of LC material provides a means to reconfigure the bandpass filter response of the FSS, by exploiting the dielectric anisotropy property of a thin layer of nematic state LC material which is sandwiched between the array as shown in Figure 3. In the unbiased (0V) state, the LC molecules are orientated parallel to the surface of the periodic arrays which are covered with a thin layer of alignment polyimide. The torque necessary to rotate the molecules perpendicular to the electrodes is obtained by applying a voltage between the biasing layers. The permittivity of the LC substrate therefore varies between two values  $\epsilon_{//}$  (0V state) and  $\epsilon_{\perp}$  (biased state), with practically no current consumption. The electrical path length in the substrate can therefore be altered electronically by the dielectric anisotropy of the liquid crystals which is defined as  $\Delta\epsilon_{eff} = \epsilon_{//} - \epsilon_{\perp}$ .

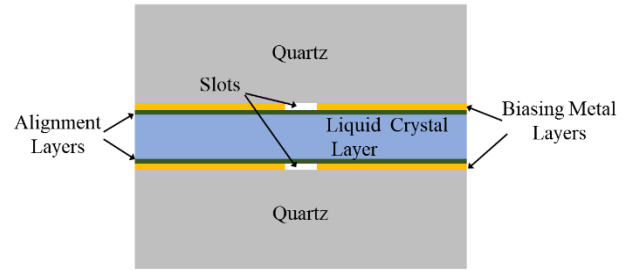


Figure 3: Sectional view of a LC based FSS cell with liquid crystal interlayer and quartz cladding.

The design was carried out in CST Microwave Studio [6] and involved cascading two FSS layers with a small gap separating the screens, as shown in Figure 4 (a) and (b). The numerical model uses permittivity and loss tangent values obtained for commercially available LC material. The device was modelled using two quartz wafers ( $\epsilon_r = 3.78$ ), and a thin layer of GT3-23001, which is manufactured by Merck for microwave applications. When fully biased the LC mixture provides  $\epsilon_{\perp} = 2.5$ ,  $\tan\delta_{\perp} = 0.0143$  and unbiased  $\epsilon_{//} = 3.3$ ,  $\tan\delta_{//} = 0.0038$ .

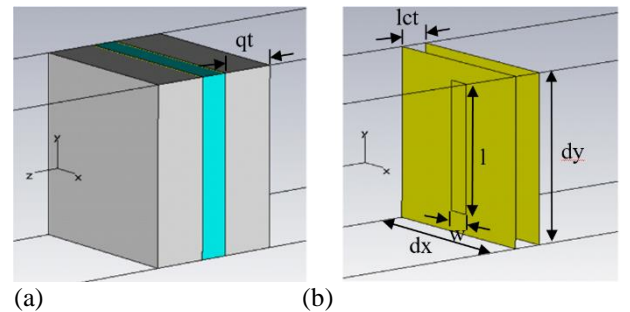


Figure 4: (a) FSS LC multilayer structure, (b) exposed copper layers with slots. Dimensions of unit cell  $dx = 310$ ,  $dy = 325$ , slot length  $l = 247$ , slot width  $w = 40$ ,

quartz thickness  $qt = 98.5$ , liquid crystal thickness  $lct = 50$  ( $\mu\text{m}$ ).

Preliminary computations depicted in Figure 5, show that an ‘on’ bandwidth of 3.7% with 0.6 - 1 dB insertion loss obtained at 330 GHz, for  $\epsilon_{\perp} = 2.5$   $\tan\delta_{\perp} = 0.0143$ .

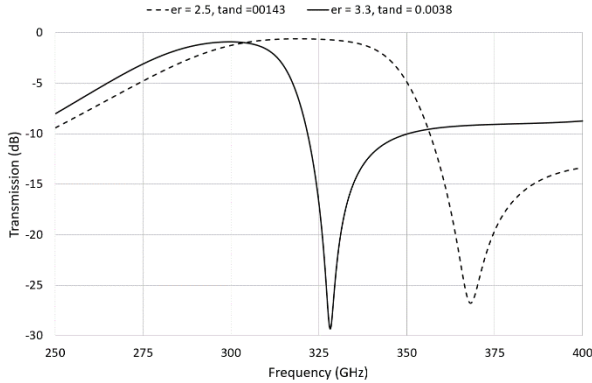


Figure 5: Transmission performance of the FSS operating at TM 45° incidence. Passband covers 323.6 – 335.8 GHz with losses 0.6 - 1 dB. Switchable 323.6 – 335.8 GHz stopband provides isolation > 12dB.

When the dielectric constant of the material is switched to  $\epsilon_r = 3.3$   $\tan\delta_r = 0.0038$  the passband transmission drops providing ‘off’ switching and transmission falls by a minimum of 12 dB, effectively attenuating the transmission through the FSS.

#### IV. PIEZOELECTRIC ACTUATED FSS

Using this approach, the bandpass response can be controlled by the proximity of a thin layer of high permittivity dielectric material and a periodic slot FSS. The amplitude and phase of waves passing through or reflecting off the dielectric and FSS surfaces are determined by the electromagnetic interaction between the layers. The FSS [7] comprises a freestanding mesh of strongly shaped slot elements formed into a thin 12.5  $\mu\text{m}$  metal screen. The design lends itself to this concept and is used to demonstrate device operation, not ultimate performance. The actuation method uses piezoelectrics to reconfigure the dielectric layer, providing spatial translation in front of the FSS’s metal surface. In operation this increases the air gap between the two layers, and shifts the FSS transmission resonance higher in frequency. Using a high permittivity material such as silicon ( $\epsilon_r$  11.9) gives a significant amount of frequency change when the layer is translated within the range of the piezoelectric actuator (0 - 20 $\mu\text{m}$ ). As the dielectric layer moves away from the FSS the resonant frequency returns to the freestanding case. A sectional view of the actuation

method is shown in Figure 6. The silicon diaphragm layer when translated by 6 - 16  $\mu\text{m}$  from the mesh surface produces a 26 GHz frequency shift of the passband which is centred around 275 GHz, this is depicted in Figure 7. It also shows that the arrangement provides switching between ‘on’ and ‘off’ states with 0.3 - 0.65 dB insertion loss, and high isolation of over 15 dB between 270 – 280 GHz. The physical movement between the two screens can be precisely controlled by the piezoelectric actuators positioned at the edges of the device, their location is shown in Figure 6.

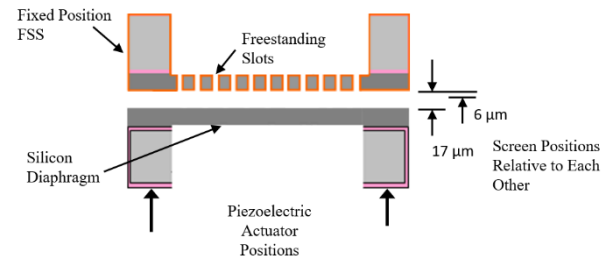


Figure 6: Piezoelectric actuation method.

To improve the devices isolation performance a two-layer structure was formed. The simulation model is shown in Figure 8 along with transmission results for TE 45° incidence. These demonstrate a 10 GHz passband with slightly higher insertion loss 0.5 - 0.9 dB, but significantly improved isolation > 35 dB over the same frequency range.

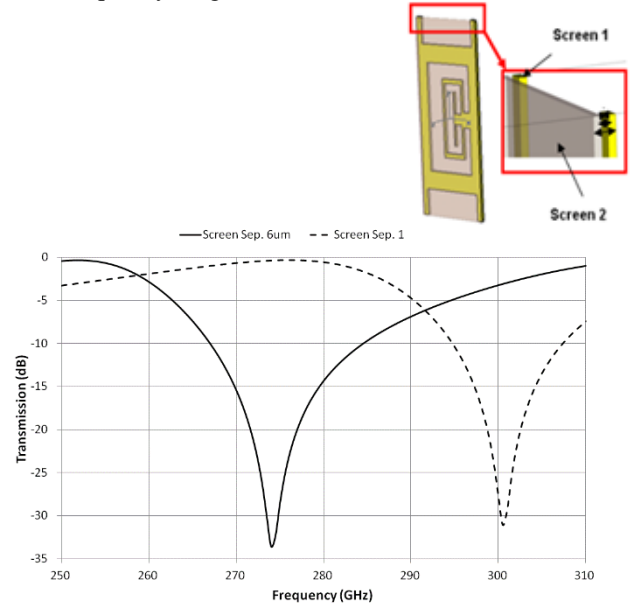
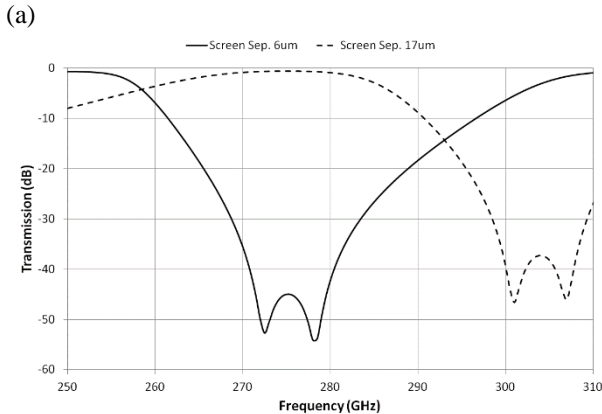
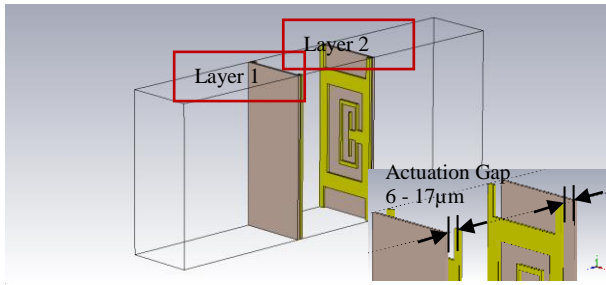


Figure 7: (top) Reconfigurable FSS, (bottom plot) Simulated spectral response modelled from 250 – 310 GHz, passband frequency from 270 - 280 GHz, 0.3 - 0.65 dB insertion loss, switching to a minimum of 15 dB isolation.



(b)  
Figure 8: (a) Two-layer reconfigurable FSS model, (b) transmission simulated spectral responses over the frequency range 250 - 310 GHz. Passband/ Stopband centred around 275 GHz, switching bandwidth 270 - 280 GHz, from 'on' 0.6 - 0.9 dB insertion loss, to 'off' minimum isolation over 37 dB.

## V. CONCLUSIONS AND FUTURE WORK

The simulated spectral results demonstrate that both actuation methods, LC and piezoelectric can be used to implement an FSS based calibration switch. The predictions made over the frequency range 250 – 400 GHz, demonstrate RF performance that would fit with radiometer operation that prioritised reduced weight and power consumption over low insertion loss. The LC structures insertion loss was between 0.6 - 1 dB with minimum channel isolation of 12 dB over a 10 GHz bandwidth at 330 GHz. For the piezoelectric operated single layer FSS at 275 GHz the results were improved with 0.3 - 0.65 dB insertion loss and isolation over 15 dB. When this was modelled as a two-layer FSS a significant increase in isolation to over 37 dB was achieved, with insertion loss in the 0.6 – 0.9 dB range.

These preliminary results are very encouraging, and the next phase of the project will be to investigate the MEMS piezoelectric FSS further through manufacture and test of a single layer device to prove the concept.

## VI. ACKNOWLEDGMENTS

This work is supported by The Centre for Earth Observation Instrumentation (CEOI). <http://ceoi.ac.uk/>

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